Two Electrodes Low Voltage Input EEG Amplifier for Brain-Computer-Interface

Y.Q.Tan[1], F. Ibrahim[1] and M. Moghavvemi[2]

[1] Department of Biomedical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia.
[2] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia.

Abstract— **This paper describes the development of a bipolar EEG amplifier designed specifically for use in a brain-computer-interface (BCI). The design principle of amplifier is base on a differential amplifier followed with multiple gain amplifier units. The amplifier gain is easily modified to amplify other biopotential signals. The design circuit meets the requirement of low power consumption, high gain and low frequency response.**

I. Introduction

Brain-computer-interface (BCI) is a communication system that does not depend on the brain's normal output pathways of peripheral nerves and muscles. BCI employs either EEG activity recorded from the scalp, or the activity of individual cortical neurons recorded from implanted electrodes [1]. BCI has been introduced to record the EEG signals from subject and process the recorded signals for further application.

A complete EEG signal acquire system consists of EEG source, amplifier, filters, A/D converter and a display.

Because EEG signal has a very low level of voltage, ranging from 1μV to 100mV [2], it has to be amplified to make compatible with other devices such as displays, recorders or A/C converters for computerized equipment. A specific high gain amplifier (gain of 10,000 - 1,000,000) is required to boost signal strength up to an acceptable level required, as an input to recording devices.

Besides EEG, other important biopotential in clinical tests such as electrocardiogram (ECG), electromyogram (EMG), electrooculogram (EOG) *etc.* are also generated in low voltage range. Thus, variable gain amplifier can easily been operated to acquire various biopotential signals.

Commonly, a good amplifier requires small in dimension and low power consumption [3]. Small dimensions of design enable the modules to be used in all kinds of portable and telemetry measurements. Minimum power consumption enable the amplifier using batteries-supply, it is greatly improved safety, because no high voltages present in the amplifier cabinet, furthermore, batteries supply 'clean' supply voltage without noise.

Over the decades, various biopotential amplifiers had been designed by researchers to record the biopotential signals [3-12]. In these proposed designs, amplification of biopotential with differential amplifier is almost an axiom.

Besides the differential amplifier, the researchers had tried to improve the circuit performance by various designs, which will be discussed following:

1. Low power supply design [3,4,5,6,7,8,12]

   These designs had operated in voltage around 3V to maximum 5V. All of the circuit is suitable to operate by batteries supply and then enables portable operation. It is clear that, in the portable equipment, 50Hz notch filter and isolation amplifier can be avoided.

2. AC-coupling to filter any dc voltage[8,9,10,11]

   Biopotential signal acquisition always in the condition to collect low level ac signals in the presence of common-mode noise and dc voltage. Thus, ac-coupling technique is required to extract the ac signal and reject common-mode noise and dc voltage.

3. Driven-right-leg circuit [10,13]

   DRL circuit is used to cancel the common-mode potential of the body. In ideal case, the common-mode signal should drive to zero by the DRL circuit.

   However, the circuit still has some drawbacks. Some residual common mode potential between the body and earth always measured. Reduced rejection of higher harmonic of the interference was noticed as well as some circuit instability.

4. Simple design to miniaturize the design [3,6,7]

   A design of amplifier with few parts enables the modules been miniaturized and fabricated into PCB (printed circuit board). Besides, the design should be easy to modify to suit other biopotential acquisition.

5. Low noise circuit [3,7]

   Biopotential commonly ranging in very low lever voltage, common white noise may easily affect the interested signal. Thus, high-pass and low-pass filters are preferable to place in the circuit.

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6. High common-mode-rejection-ratio (CMRR) [5,8,9,10,12]

It is important to reject the input signal common to both inputs, and the challenge of the design is to reach a high CMRR without any trimmings.

Three op-amp amplifier integrated circuit (IC) chips had been widely used in the designs; however, these IC is no longer suitable when a monopolar measurement is required [3]. Furthermore, the commercial IC chips had had specific value of gain, which had been preset initially, and do not meet with the biopotential signal requirements. Modifications of circuit are needed to adapt these amplifiers to the applications.

Therefore, it raised the idea to design and develop an EEG amplifier using the discrete components such as transistor, resistor and capacitor, instead of IC chips.

By using the transistors, the amplifier characteristic can be easily designed and set to the desired values with the help of resistors and capacitors. Thus, the amplifier can be perfectly matched to the biopotential signal applications requirements.

II. The Proposed Designed Circuit

The proposed designed circuit is the adaptive idea from the researchers Ayaki *et al.* [14] in their design for a multi-stage microwave transistor amplifier.

As stated before, differential amplifier is the main core for a biopotential amplifier, to increase the gain of the amplifier, some gain amplification units can be added as required to achieve desired gain. High pass and low pass filter is added in the circuit in order to filter out the noise. The amplified signal is then connected to computer via a data acquisition card (DAQ card) as illustrated in the block diagram Fig. 1, The overall proposed design circuit is as shown in Fig. 2.

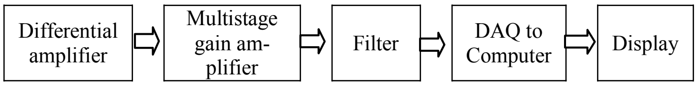

Fig. 1 Overall block diagram of the BCI system.

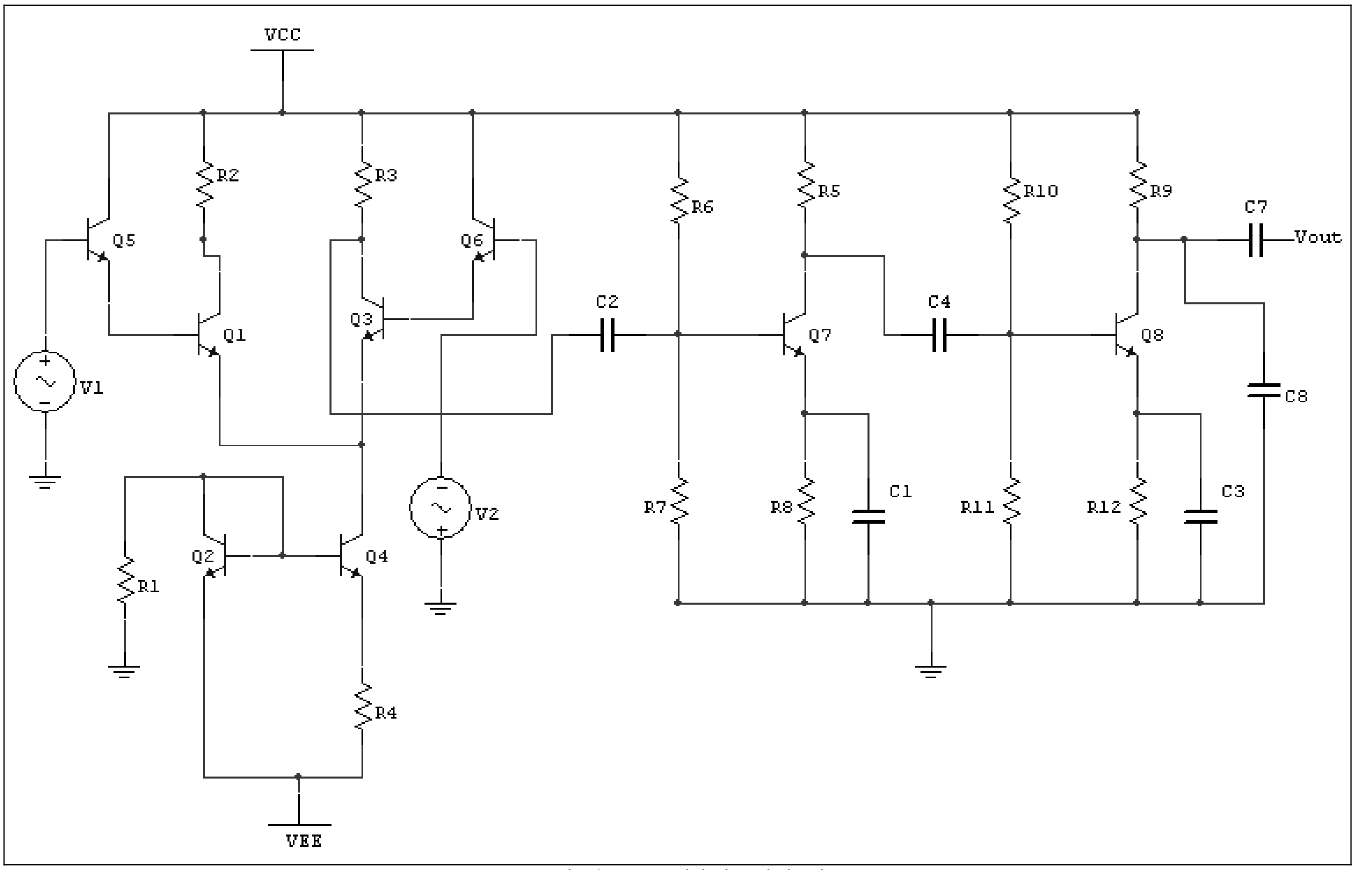

Fig. 2 Proposed designed circuit

A. Differential amplifier

The proposed designed circuit was directly constructed using the conventional transistors, resistors and capacitors, instead of using op-amp chips. As such, the desired gain is achieved by design rather than through gain modification on an op-amp.

Differential amplifier was used to amplify the difference of signals, collected from two electrodes.

Because of the high gain requirement, the bias current must be small, and this can be achieved by connecting the circuit with constant current source, such as Widlar current source. In addition, the current source can be designed to provide small current, which is not limited by the early voltage of the transistor [12].

Darlington pair is used in input part to increase the input impedance.

B. Gain stage

Based on the requirement of the biopotential amplifier, common emitter (CE) amplifier is the most suitable configuration used to provide moderate input impedance and voltage gain, and thus it had been chosen to be the gain stage for this amplifier.

With the selection of proper value of resistors and capacitors, the gain provided by this CE amplifier had been set to 20. When several CE amplifiers are connected in cascade, the resulted gain is also increase proportionally.

The total gain of the amplifier is the product of differential amplifier and multiple CE amplifiers gain. The differential amplifier gain was fixed to a value of 50 and each CE amplifier provided a gain of 20. Therefore, the total gain of the proposed amplifier can be adjusted by changing the number of CE amplifier connected in cascade.

As for the requirement of an EEG amplifier, the total gain is required to be in the range of 10,000 – 1,000,000, in order to amplify the input signal of µV to the output signal of around V.

C. AC coupling

As for the proposed circuit, some coupling capacitors had been located in CE amplifier circuit to block the dc offset voltage and increase the gain value.

However, capacitor is a frequency response element and this will affect the amplification gain of the amplifier in low frequency. Therefore, the circuit should be designed to provide a flat gain characteristic within the desired frequency, which is the EEG band.

For an ideal situation, the value of capacitors should be increase to a very large value, *i.e.* 1 Farad, to decrease the cutoff frequency towards zero Hertz [14]. However, in practical sense, increasing the value of capacitor will also increase the size of the component, which in turn will increase the total size of amplifier module. Trade off between the size of component and cutoff frequency been considered in the design.

D. Filter

The cascading capacitors and resistors in CE amplifier had forming a high-pass filter, to eliminate any low frequency noise.

Another high pass filter had placed at the output part. It is used to drain unwanted very high frequency noise, which had been created along the circuit, to ground.

III. Results and discussion

The biopotential amplifier specific for EEG signal amplification was simulated using Multisim 7 software. After the appropriate resistors and capacitors values have been identified to set the specific gain and high pass and low pass cutoff frequency, a bipolar EEG amplifier was constructed using conventional transistor, resistors and capacitors.

A. Simulation and Testing Result

An amplifier with 3 gain stages had been cascaded. The circuit had been tested using an input sinusoidal wave of 5µV, 5Hz, and resulted 1.72V sinusoidal wave, which shows in Fig. 3. This shows that the circuit can provide a gain of 344,000, compare with the 400,000 by calculated. The difference may be due to the tolerance of the components used.

Some noises had presented in the signal, such as the 50Hz noise, however, usual important clinical EEG signal falls in the range of 1-30Hz, thus the 50Hz noise will not affected the desired signal. It can further be removed used the filtering program software.

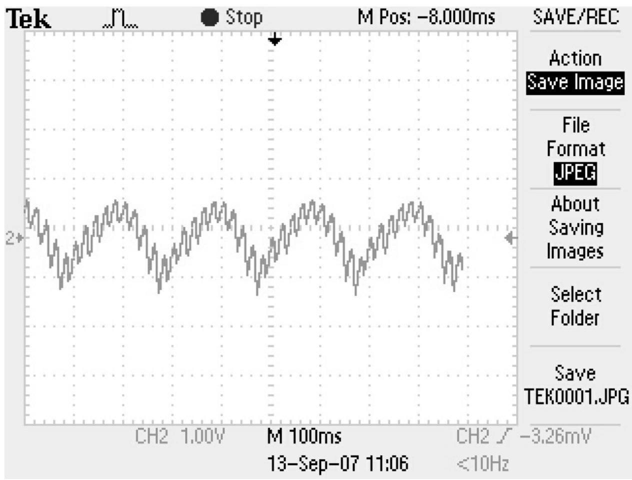

Fig. 3 Resulted output with input 5uV, 5Hz sinusoidal wave.

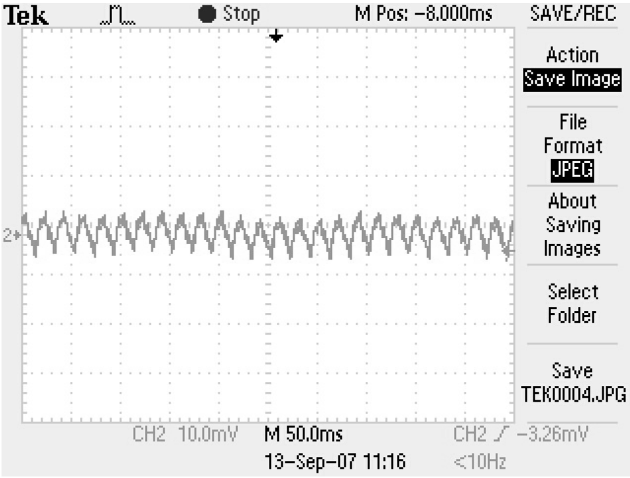

Fig. 4 Common mode input signal.

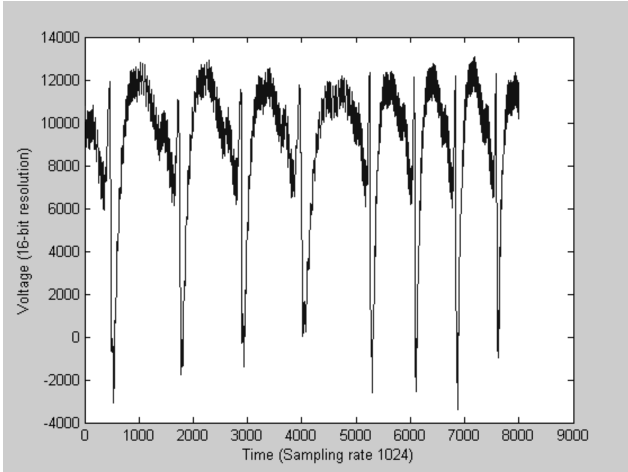

Fig. 5 Segment of the ECG acquired. Noises appear in signal.

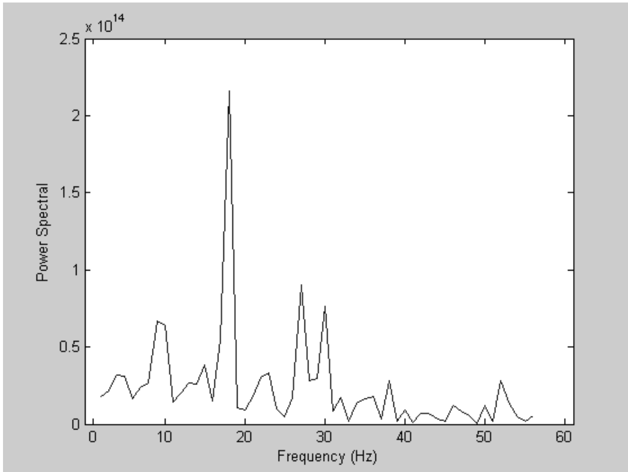

Fig. 6 The averaged power spectral plot of the EEG signals.

Fig. 4 shows the resulted signal when common mode input is applied, the output only shows the 50Hz noise.

B. Biopotential Signal

The circuit also been tested to collect the real biopotential signals, such as EEG and ECG. A gain of 86dB (20,000) amplifier is used to collect the EEG signal. The high gain is achieved by cascading the differential amplifier with 2 gain amplifier units, as shown in Fig. 2. For the ECG signal, an amplifier with gain of 60dB (1,000) is used by cascading the differential amplifier with 1 gain amplifier units.

1. ECG signal

Definition from wikipedia [15] state the electrocardiogram is a test of records the electrical activity of the heart over time.

There are few types of leads placements can be located in human body in order to collect ECG signal, includes limb leads, augmented limb leads and precordial leads.

Fig. 5 and Fig. 6 show the ECG signal collected at position V1 in precordial electrode placement (refer to [15] for electrodes placement). At the position V1, the QRS complex is inversed with the normal.

Noise appeared in the signal, however, in the average power spectral plot, it shows that without any additional filter program, the noise level is not affected the desired signal, which is in the range of 1-40Hz.

2. EEG signal

Fig 7 shows the EEG signal been collected. The electrode is placed at position Cz and signal is collected while subject is in sitting position, relax and eye closed.

In Fig. 8, it is clear that a strong signal had been form in the frequency range around 10Hz, and this had proved that alpha band EEG (8-12Hz) of the subject had been collected. Refer to [16] for detail of EEG signal.

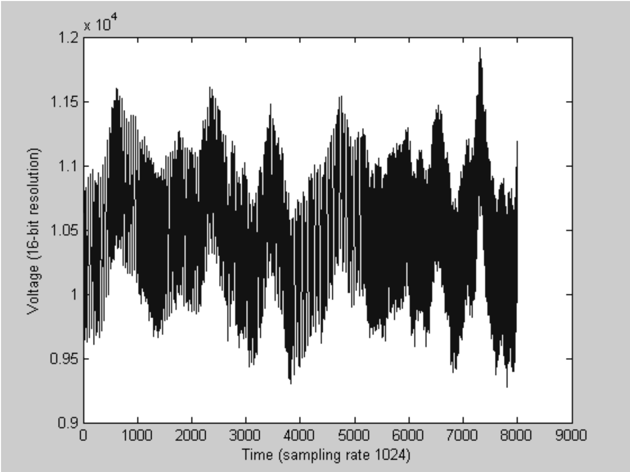

Fig. 7 Segmented EEG signal collected with amplifier built.

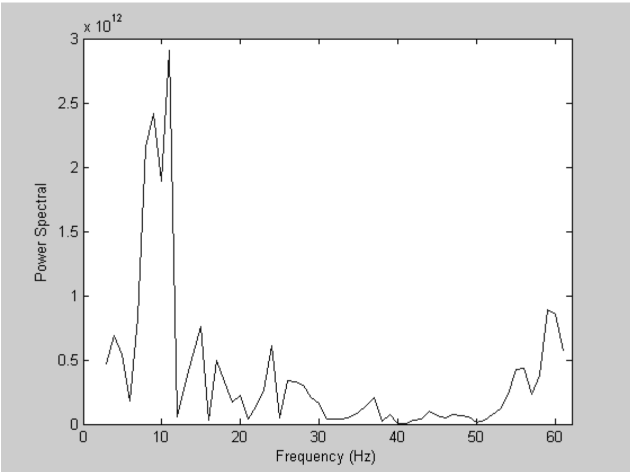

Fig. 8 The averaged power spectral plot of the EEG signals.

C. Frequency Response

Some cascading capacitors had been located in CE amplifier in order to block any dc voltage. At the same time, these capacitors with resistors in the circuit had form a high pass filter to eliminate any low frequency noise.

A capacitor is placed in parallel at the output part of circuit to ground, to drain very high frequency noise to ground.

The bandwidth of the circuit had set to 1 and 100Hz by selection of proper components' value.

In practical, there are some difference between the calculation value and measured value. The difference may caused by the tolerance of components used.

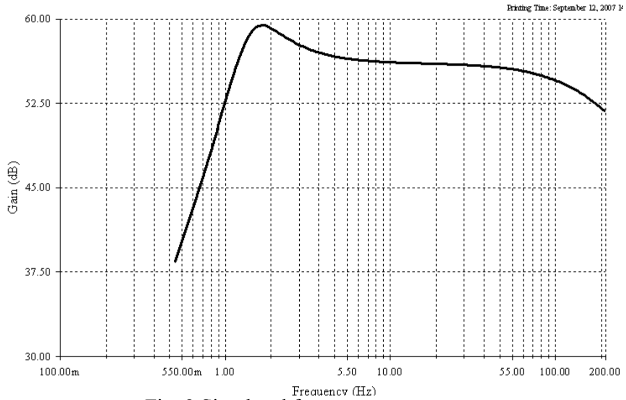

Fig. 9 Simulated frequency response.

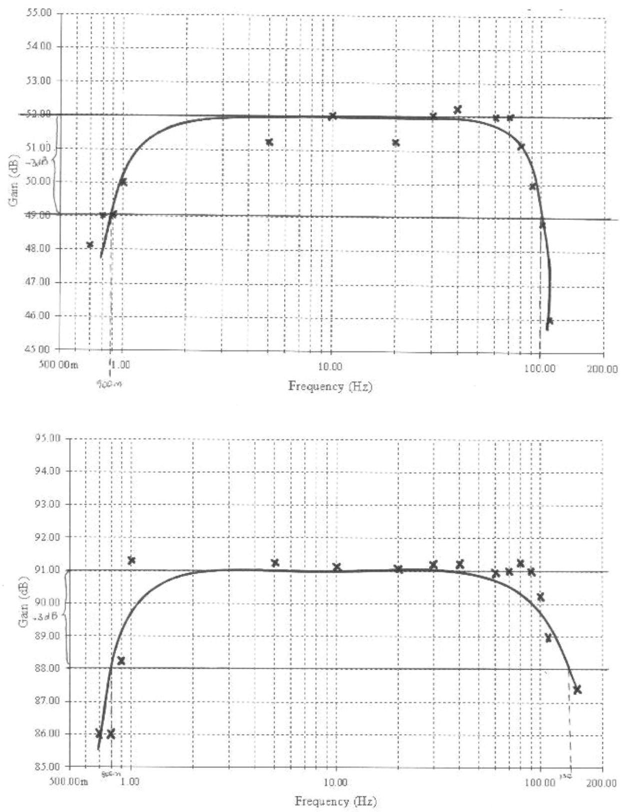

Fig. 10 Actual frequency response for amplifier used to collect ECG (Top) and amplifier used to collect EEG signal (Bottom).

The summary of the properties of this amplifier as shown in the table below:

TABLE 1

AMPLIFIER'S SPECIFICATION

Input impedance	46.8Mohm
Bandwidth	0.8-100Hz (important clinical signal fall in range 1-30Hz)
CMRR	87.6 (above the minimum required, 80dB)
Min. input	+- 2.5uV (with 3 gain amplifier units)
Max. input	+- 30mV (with 1 gain amplifier units)
Power consumption per channel	0.68mA * 10V = 6.8mW

IV. Conclusions and future works

A novel design of simple bipolar EEG amplifier has been developed using basic electronic components, such as transistors, resistors and capacitors.

The design had satisfied the requirement of low power consumption, high gain and low frequency response.

The gain and bandwidth can be easily modified and tuned to amplify other biopotential signals such as electromyogram (EMG) or electrocardiogram (ECG), by simply added the number of gain amplifier units to achive the desired gain.

Many other factors will determined the performance of an amplifier, such as white noise signal, 50Hz noise from power supply, time reliability, temperature, connection of electrodes and output connection to DAQ system. Therefore, future improvement and testing is required to prove the performance and reliability of this proposed design. For further improvement, the designed circuit can be fabricated into an integrated circuit (IC) chips.

References

1. J.R. Wolpaw, N. Birbaumer, D.J. McFarland, G. Pfurtscheller, T.M. Vaughan, “Brain-computer interfaces for communication and control.” *Clin. Neurophysiol*. Vol. 113, pp. 767–791, 2002.
2. R.M. Rangayyan, *Biomedical Signal Analysis*. Wiley-Interscience, New York, 2001.
3. A.C. Metting van Rijn et al, “High quality recording of bioelectric events Part2.” *Med. & Biol. Eng. & Comput.* Vol. 29, pp. 433-440, 1991.
4. A.C. Metting van Rijn et al, “The isolation mode rejection ratio in bioelectric amplifiers.” *IEEE trans. On BME*. Vol. 38(11), pp. 1154-1157, 1999.
5. E.M. Spinelli, N.H. Martinez, M.A. Mayosky, “A single supply biopotential amplifier.” *Medical Engingeering & Physics*. Vol. 23, pp. 235-238, 2001.
6. A.C. Metting van Rijn, A. Peper, C.A. Grimbergen, “Instrumentation amplifiers for bioelectric events: a design with a minimal number of parts.” *Med. & Biol. Eng. & Comput.* Vol. 32, pp. 305-310, 1994.
7. L. Badillo, V. Ponomaryov, E. Ramos, L. Igartua. “Low noise multi-channel amplifier for portable EEG biomedical applications.” Proceedings of the 25th Annual International Conference of the IEEE EMBS, Cancun, Mexico, 2003, pp.3309-3312, 2003.
8. D. Dobrev, “Two-electrode low supply voltage electrocardiogram signal amplifier.” *Med. & Biol. Eng. & Comput.* Vol. 42, pp 272-276, 2004.
9. E.M. Spinelli, M.A. Mayosky, “AC coupled three op-amp biopotential amplifier with active DC suppression.” *IEEE Transaction on Biomedical Engineering*. Vol. 47(12), pp. 1616-1619, 2000.
10. E.M. Spinelli, R. Pallas-Areny, M.A. Mayosky, “AC-coupled front-end for biopotential measurements.” *IEEE Transaction on Biomedical Engineering*. Vol. 5(3), pp. 391-395, 2003.
11. F. Rodes, O.Chevalieraz, E. Garnier, “AC_coupling Instrumentation Amplifier Improves Rejection Range of Differenial DC Input Voltage.” EDN, 2004. http://www.edn.com/article/CA454643.html
12. D. Dobrev, “High-CMRR Instrumentation Amp Work with Low Power Supply Voltages.” EDN, 2003. http://www.edn.com/article/CA324407.html
13. C.L. Levkov, “Amplification of biosignals by body potential driving. Analysis of the circuit performance.” *Med. & Biol. Eng. & Comput.* Vol. 26, pp 389-396, 1988.
14. K. Ayaki, E. Igarashi, Y. Kajiwara, “A 4-Hz Multistage Transistor Amplifier.” *IEEE Transaction on Microwave Theory and Techniques*. Vol. 17(12), pp. 1072-1077, 1969.
15. Wikipedia at http://en.wikipedia.org/wiki/Electrocardiogram
16. Wikipedia at http://en.wikipedia.org/wiki/Electroencephalography